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Transportation Vibration Data for Klystron Experimental Hardware

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Disclaimer

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To: Rick Cross

From: Steve Jensen

Subject: Transportation Vibration Data for Klystron Experimental Hardware

Purpose:

This memo discusses the over-the-road vibration and shock data that was captured while transporting a klystron unit from the Stanford Linear Accelerator (SLAC) facility in Menlo Park, CA to the Lawrence Livermore National Laboratory (LLNL) main site (B381). The klystron was shipped over the road in an air ride truck on May 1, 2012 in a specially designed wooden crate with an aluminum support frame for reinforcement. The klystron unit, itself, was suspended from the frame using wire cable spring isolators to help mitigate unwanted shock and vibration.

The motivation for capturing vibration data on this hardware was to help better understand the dynamic loading and handling shocks that could be experienced during transportation. Additionally it was to validate that the isolation system of cable springs would in fact mitigate the peak accelerations and help preserve the structural integrity of the klystron unit, which is considered fragile. A picture of the klystron unit is shown to the right in a partially assembled shipping crate.

Figure 1: Klystron hardware, shown on cable spring isolators in shipping crate.

Transportation Details:

As stated earlier, the shipment was made on Tuesday, May 1, 2012. A review of the data collected shows that the recorder was turned on at 9:32 am, however the data seems to suggest that actual transportation didn't commence until roughly to 2:27 pm. The data suggests the total duration of the transportation, including any handling, was roughly 2 hours and 30 minutes because all data collected after 5:00 pm shows a static low grms value of 0.032 (idle/rest data). Temperature inside the truck ranged between 64 – 71 °F, with the mean around 66 °F. The humidity ranged between 46 % and 50%, with a mean around 49%.

The general route taken by the truck was by way of Interstate 280 to Interstate 92, to Interstate 880; to Interstate 238 to Interstate 580 to Vasco Rd. Little else of the transportation details are known at this time. Items of interest which the MegaRay Program may know and should document are: the shipping container weight, size and model of the truck, whether or not additional equipment was transported on the truck thus affecting the load on the air suspension, where the load was placed (i.e over the rear axles?), and how the load was secured to the trailer (i.e. straps, chains, etc). All of this information will help to define the boundary conditions that correspond to the ride quality. Any improvements in ride quality would start with a close examination of the transportation details.

Instrumentation Setup:

Vibration and shock data was collected using a Lansmont SAVER 9X30, which is a portable data acquisition system that runs on two 9 Volt batteries. The DAQ system has an internally integrated tri-axial accelerometer with 6 additional input channels on the exterior of the box for either 6 single axis accelerometers or two tri-axial accelerometers. The software setup of this system allows the user to allocate memory to either signal triggered events or timer triggered events. Signal triggered events (such as shock pulses) are recorded every time a set acceleration threshold is exceeded, while timer triggered events are activated on a set clock cycle. The user can specify by way of a slider bar what percentage of the memory is to be used for recording either signal or timer triggered events.

For this shipment the DAQ system was set to record 215 signal triggered events with a sample rate of 10 kHz, a duration of 250 milli-seconds per event, and a trigger threshold of 1 G. The timer triggered events were set to be recorded every 5 minutes at a sample rate of 2.5 kHz for a duration of 4 seconds. The memory allocation split (20/80) allowed for 379 timer triggered events to be recorded. For both data types the data retention mode on the DAQ was set to a "max overwrite" condition, meaning any incoming high level event would overwrite the lowest magnitude event if the memory buffer became full. This setting helped to ensure that the highest level events were recorded and retained.

Three locations were picked on the klystron unit hardware to place a tri-axial accelerometer. Position #1 was on the base of the aluminum frame as shown in Figures 2a and 2b. This location is where the DAQ was mounted; therefore the internal DAQ accelerometer was utilized to measure data at this location. This location was used to represent vibration input from the truck to the shipping crate. It was positioned near the edge of the frame because it represented a more structurally "stiff" path to the truck bed. Position #2 was on the bottom support plate for the klystron unit (see Figure 3), while Position #3 was on the upper plate, which was supported by the wire spring isolators (see Figure 4). Positions 2 and 3 were chosen to help identify what dynamic amplification or attenuation might exist between the base input and the support locations for the klystron unit.

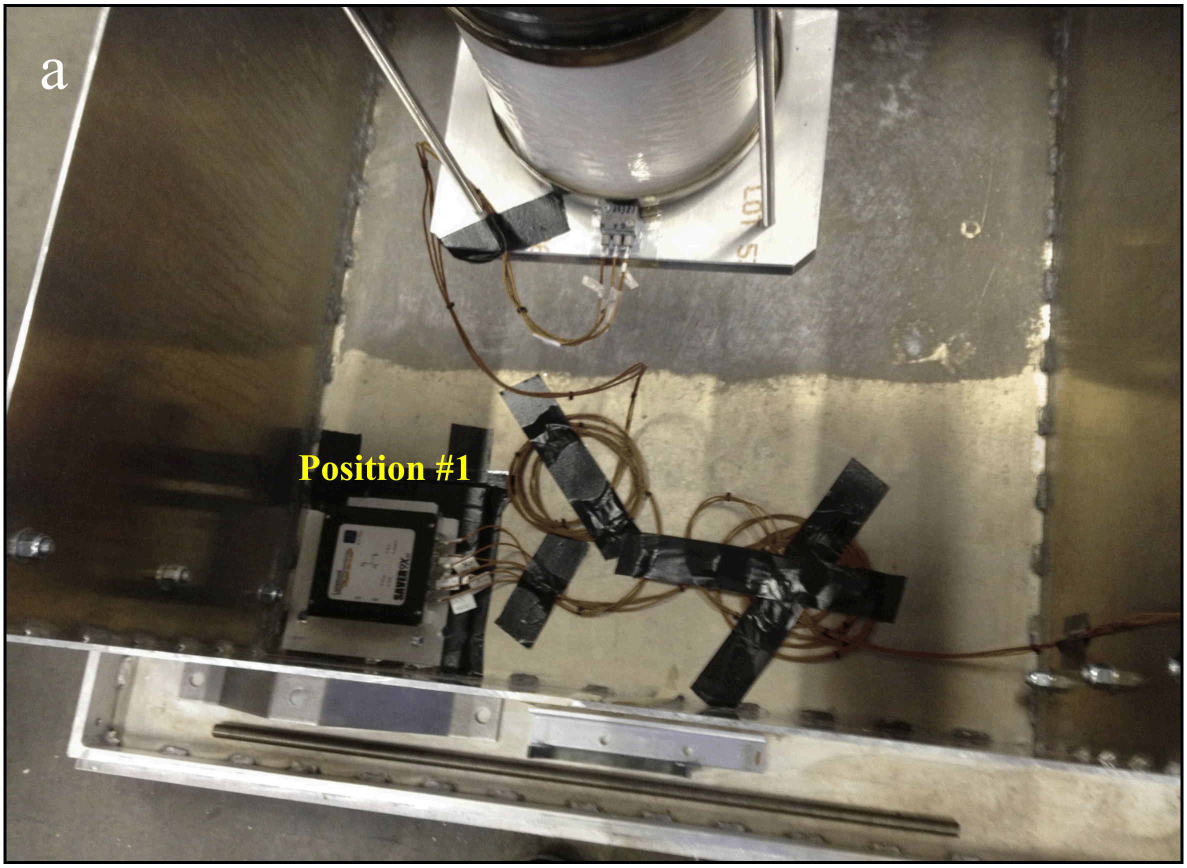
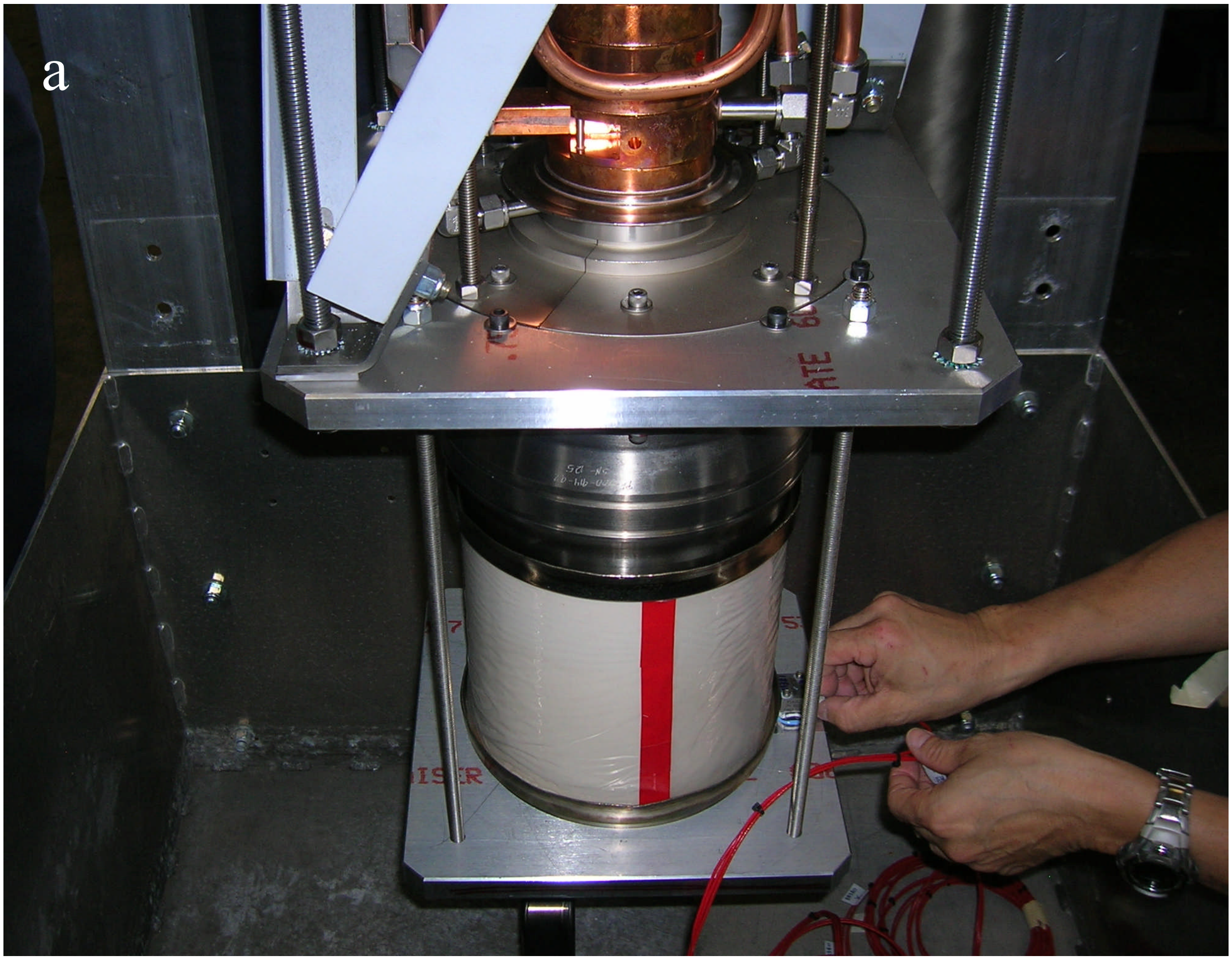


Figure 2: a) View of Lansmont DAQ unit mounted on base of aluminum frame to capture base input shock and vibration. B) Close up view of DAQ unit.



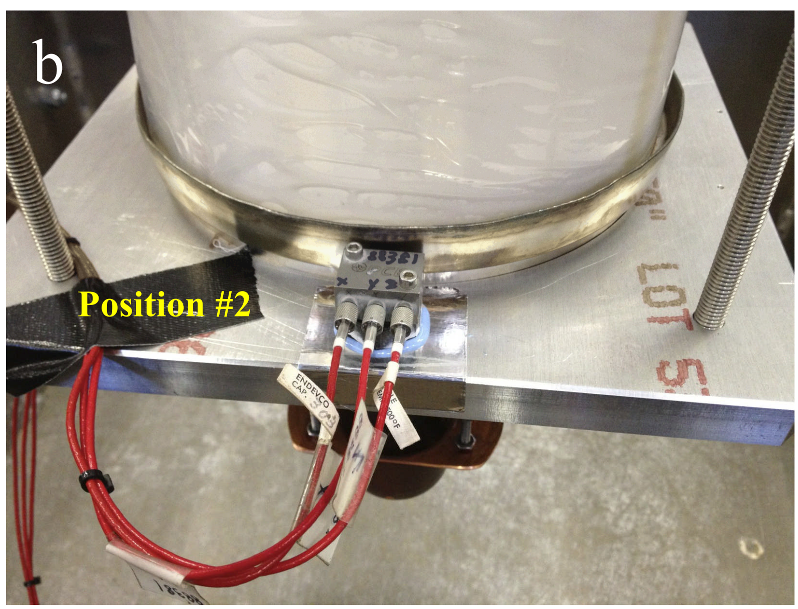
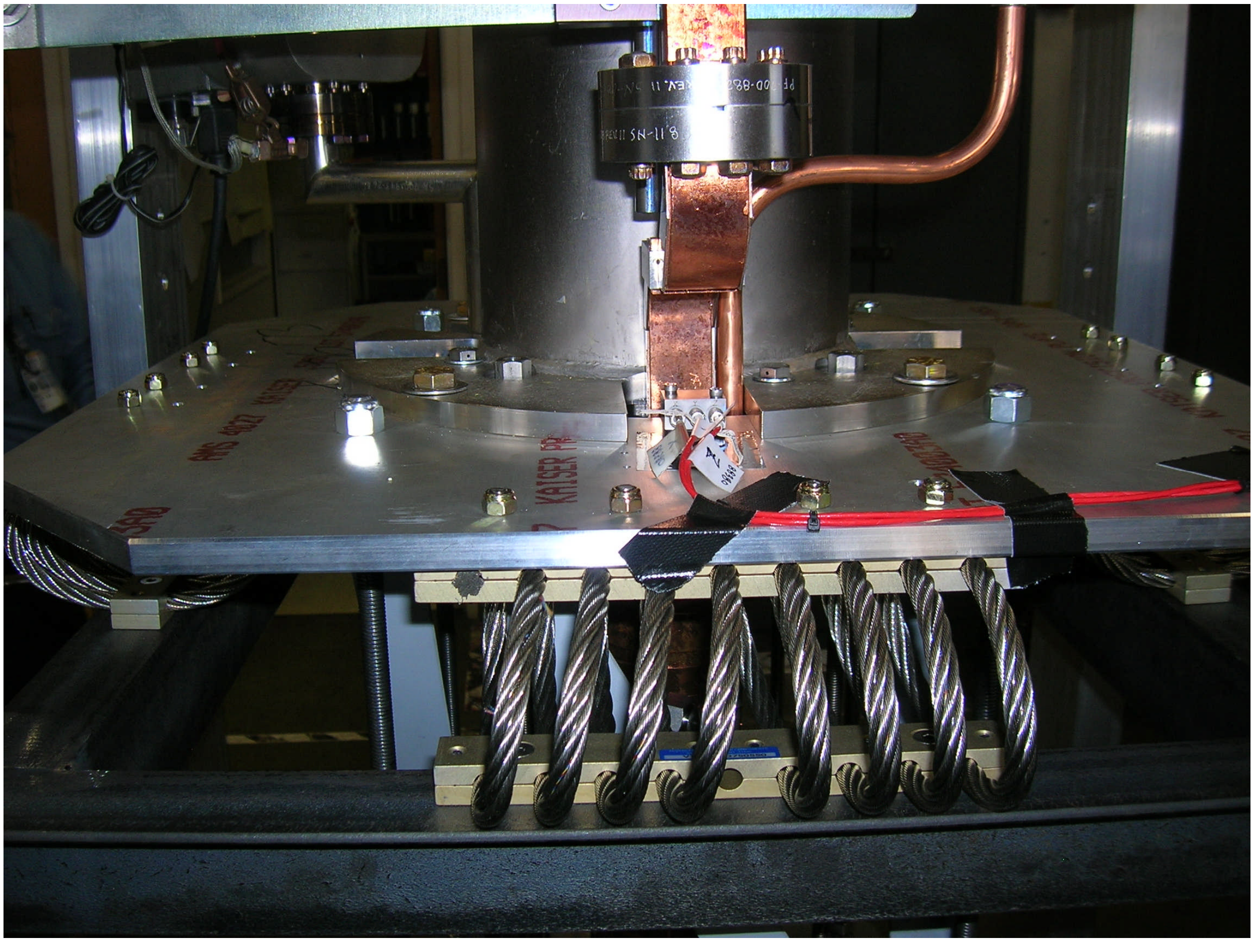


Figure 3: a) View showing location of Position #2, lower support plate. b) Close up view of accelerometer in Position #2.



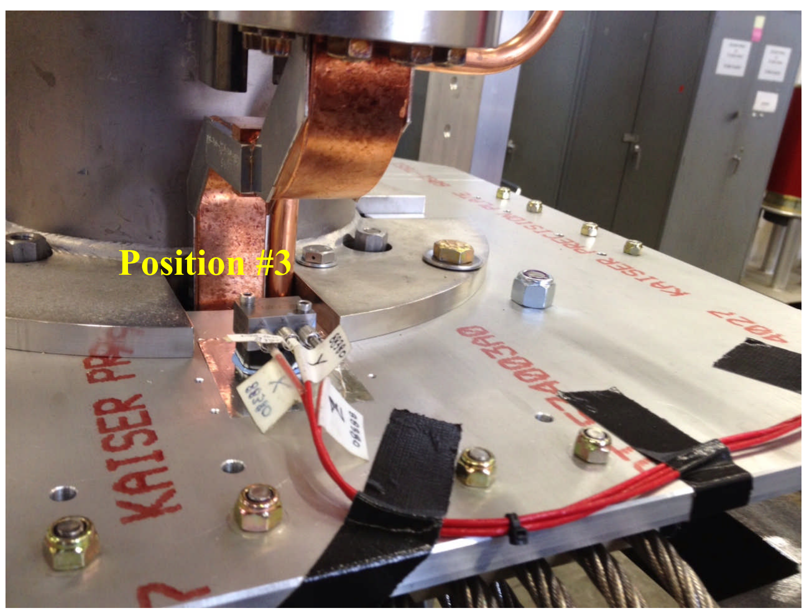


Figure 4: a) View showing location of Position #3, upper support plate. b) Close up view of accelerometer in Position #3.

Vibration Results:

For the purposes of this memo the coordinate system used to describe the different axes is defined as follows: the X-axis is in the direction of travel for the vehicle, the Y-axis is in the lateral direction with respect to the truck, and the Z-axis is in the direction of gravity.

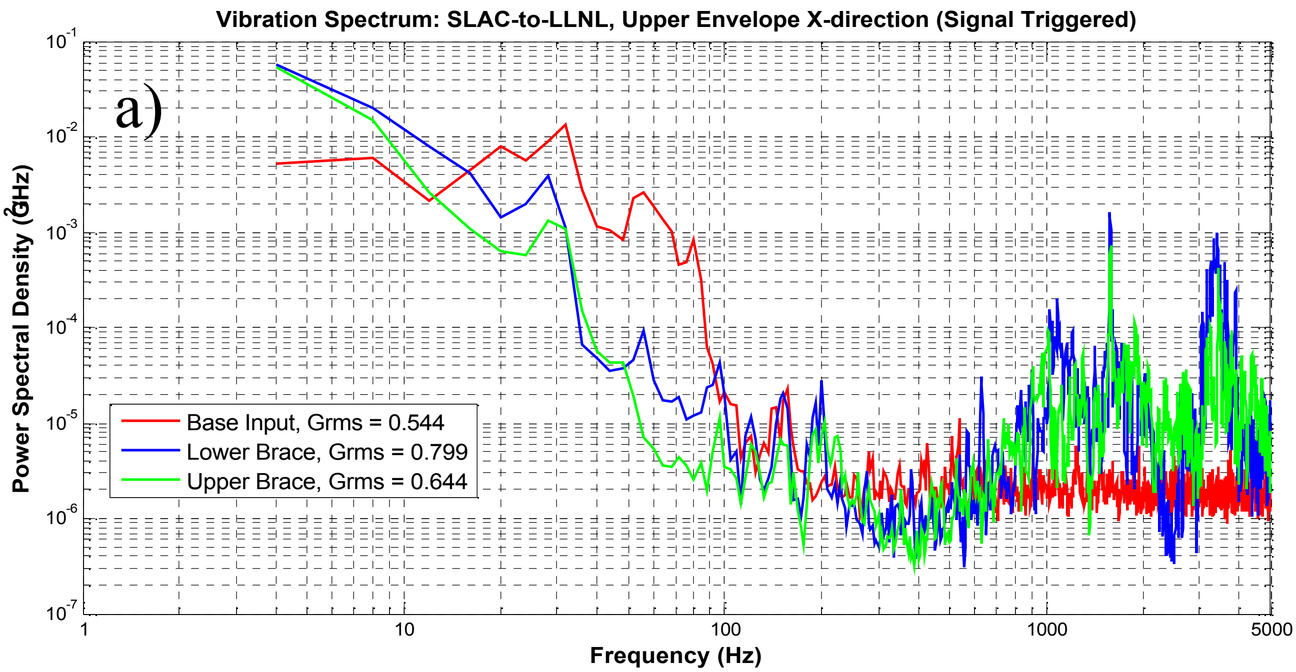
The vibration data collected was processed into Power Spectral Density (PSD) ensembles and an upper envelope was calculated from this data that represented the maximum expected spectral magnitude over the entire frequency range. This was done in a statistical manner for each frequency bin. Integration under this upper envelope curve gives the mean square of the maximum expected signal and the square root of this is simply the Grms of the signal (rms = root mean squared). The Grms of the signal is equal to the standard deviation (σ), assuming a zero mean. If a Gaussian distribution is assumed, which is a reasonable assumption for random vibration, the probability of the signal being at or below the Grms value is 68.26%

As for the expected peak magnitude, there is no deterministic relationship between the peak-G of a random vibration signal and the rms value; it is much more complicated and statistical in nature. However, the peak value of a stationary random time history is typically 3 or 4 times the rms value (3σ & 4σ). Common design practices assume a factor of 3 for hardware calculations, with 4 being a more conservative estimate.

Figures 5a, 6a, and 7a below show the calculated PSD upper envelopes for the signal triggered data collected during transit between SLAC and LLNL (B381), while Figures 5b, 6b and 7b show the calculated PSD upper envelopes for the timer based data collected during transit. Signal triggered events more often than not were found to be shock inputs to the system, but this is not a hard rule. By definition a signal triggered event is any event where at least one of the sensor channels exceeded the pre-set threshold, which for this trip was set to 1 G for all channels.

As might be expected, the signal triggered data shows higher Grms values, however what wasn't expected was that accelerometer signals on the klystron hardware showed much higher response levels over the base input at the high frequency end (>1000 Hz). This wasn't anticipated because the klystron was supposed to be isolated by the cable springs. Normally for an isolated system (i.e. a system supported by cable springs) the high frequencies would be attenuated after the resonant peak, which for the klystron unit appears to be around 4 – 5 Hz. This does hold true for the timer based signals, because the frequency content is roughly an order of magnitude less than the base input at frequencies beyond 100 Hz.

High frequency content on an isolated system is indicative of a shock induced rattle or collision of metallic parts. Looking at the time history data files for many of the signal-triggered events confirmed this suspicion (see Figures 10 – 13). It appears from the data that the klystron unit is impacting something sporadically during transportation. The "signal triggered" time histories on the klystron unit show a dominant frequency component around 4 – 5 Hz which is most likely the resonant frequency of the cable spring isolators, however intermittently a high frequency impact is shown superimposed on the time signal. It seems to suggest that there is a displacement limit for some piece of hardware or component and that excessive motion is causing components to bump together thus introducing a high frequency shock to the system. Not all signal triggered events show high frequency impacts; Figure 14 shows a base input shock but no substantial response from the klystron hardware. This is more indicative of how an isolated system should respond if no displacement limitations are present thus no impacts are experienced.



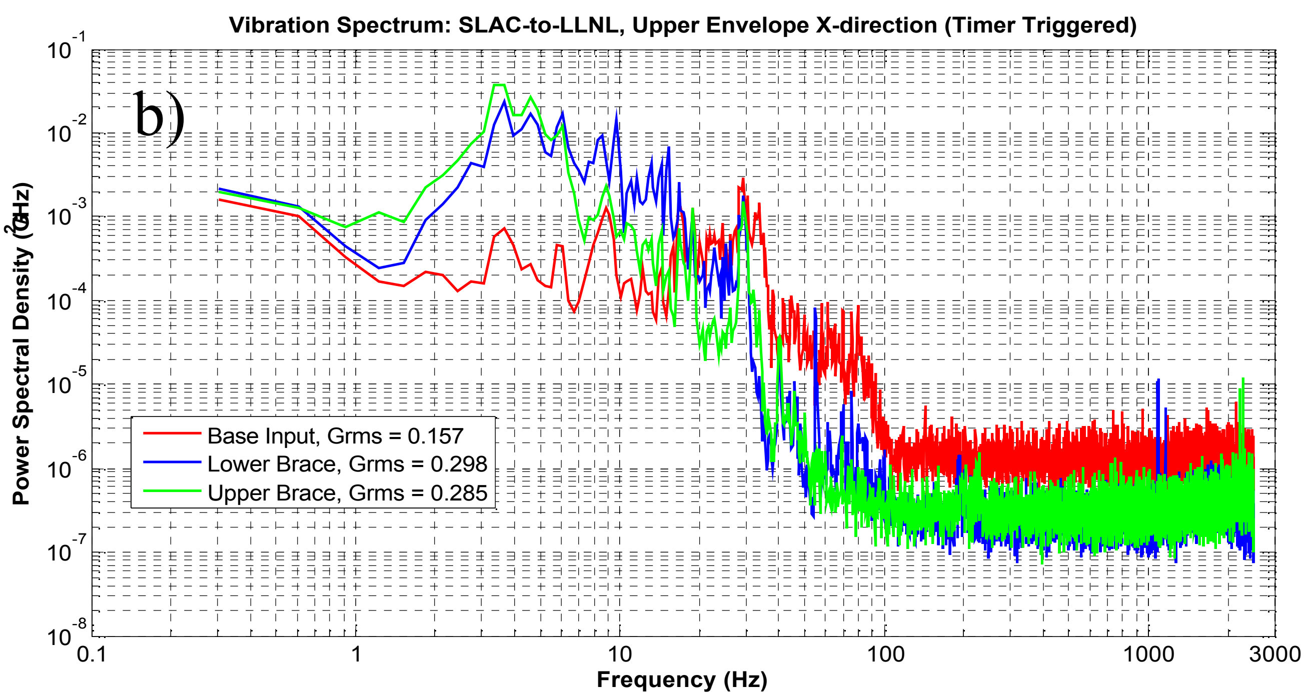
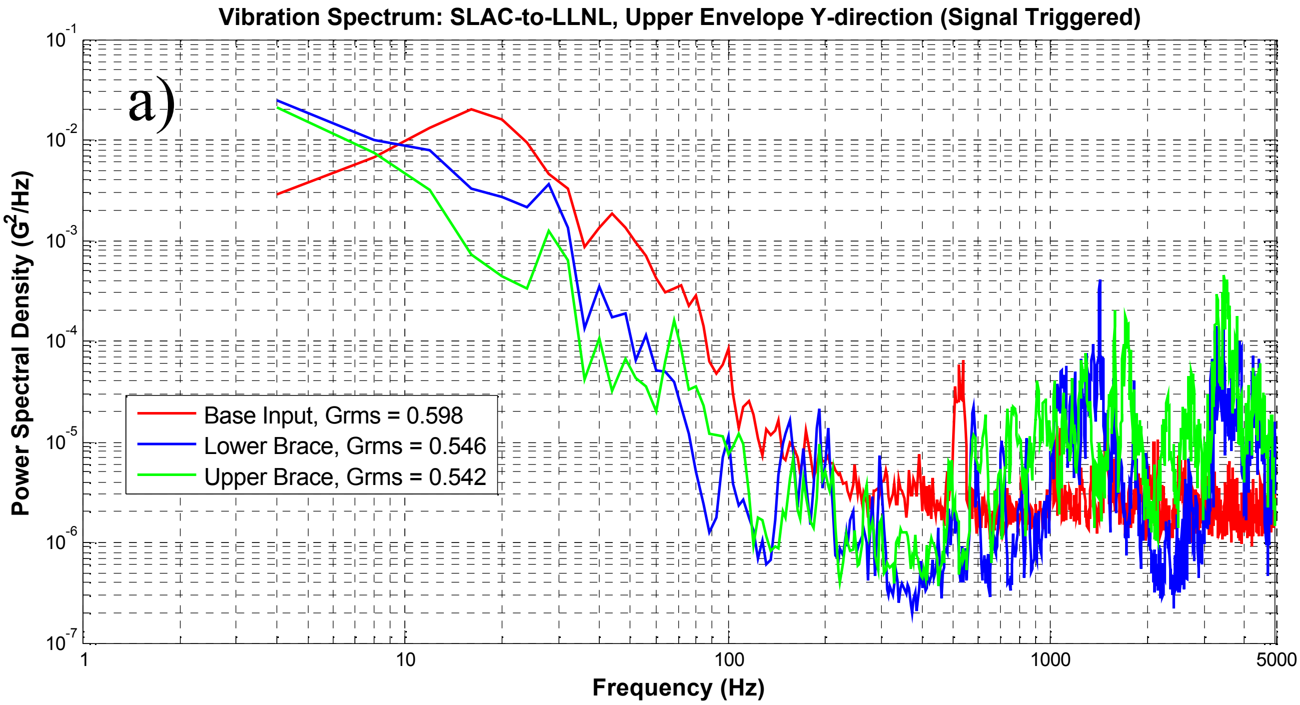


Figure 5: a) Upper PSD envelope for X-direction "Signal Triggered" data
b) Upper PSD envelope for X-direction "Timer Triggered" data



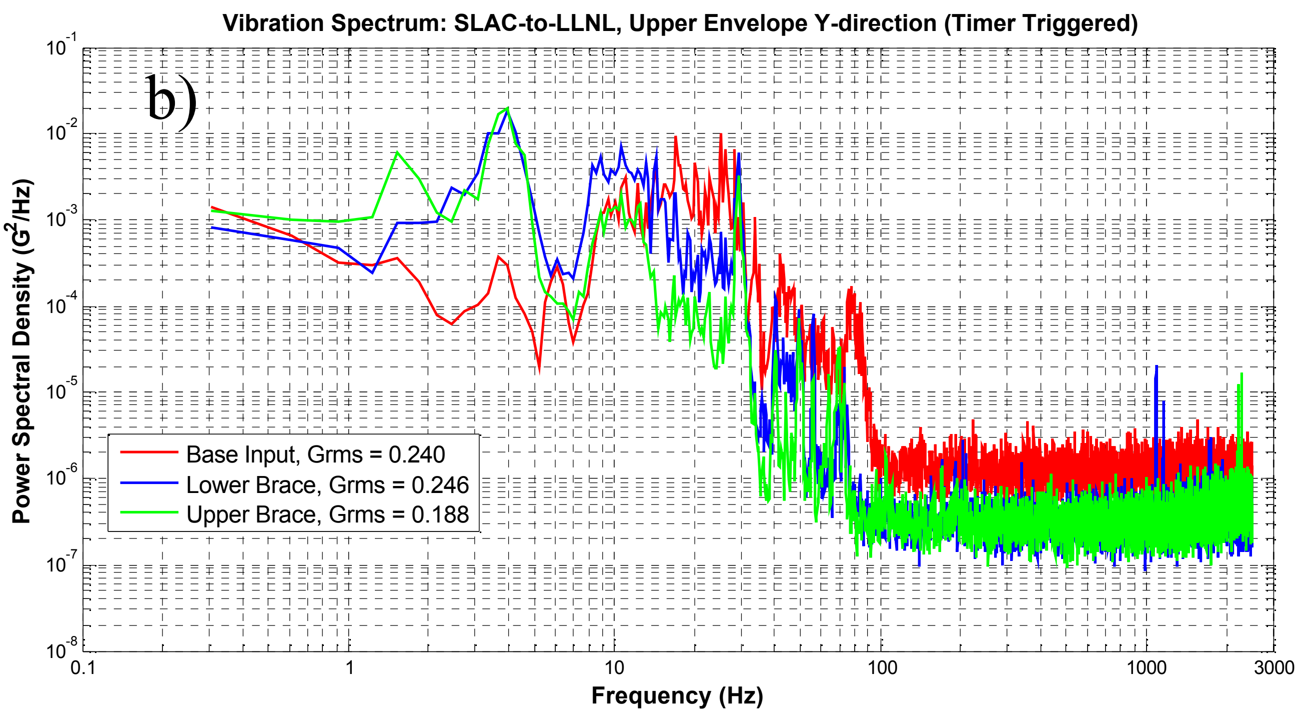
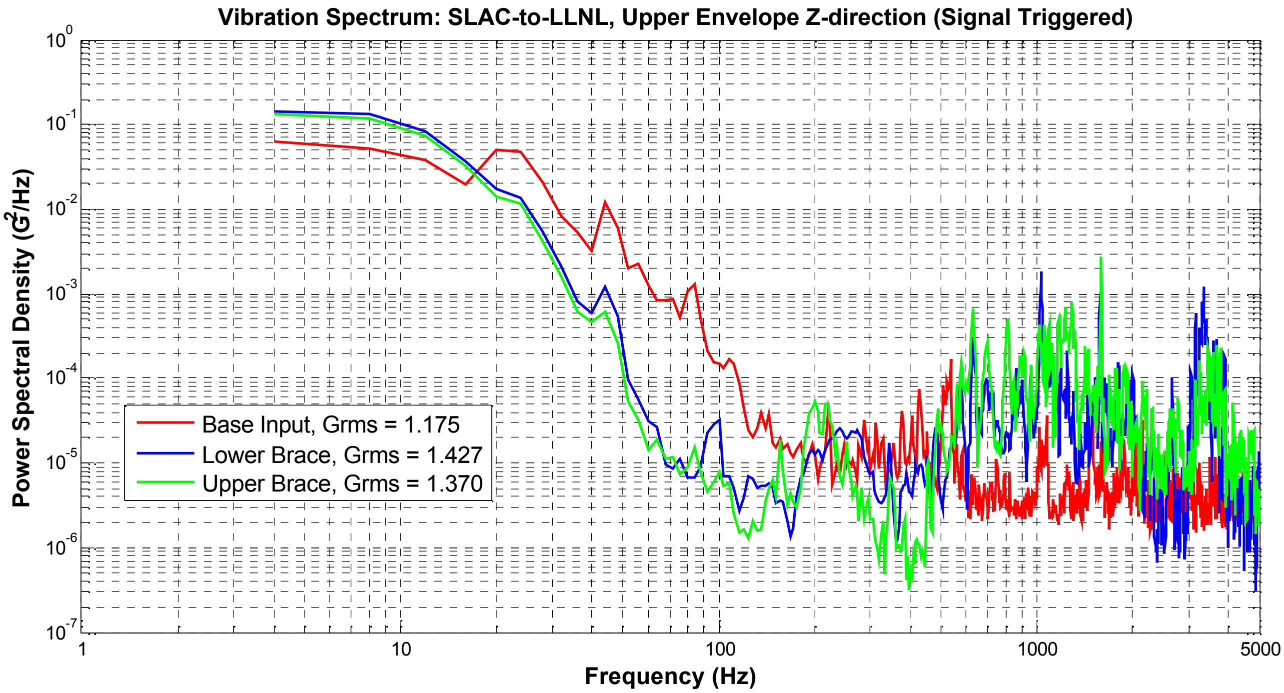


Figure 6: a) Upper PSD envelope for Y-direction "Signal Triggered" data
b) Upper PSD envelope for Y-direction "Timer Triggered" data



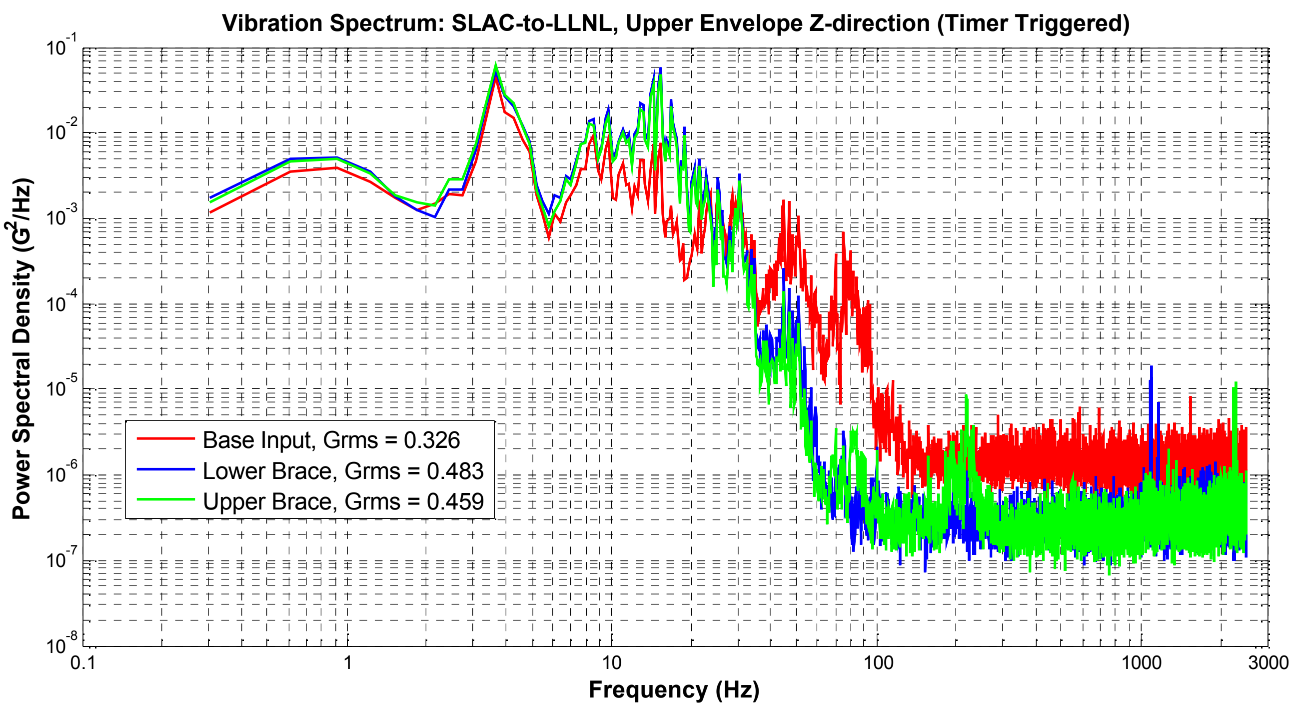


Figure 7: a) Upper PSD envelope for Z-direction "Signal Triggered" data
b) Upper PSD envelope for Z-direction "Timer Triggered" data

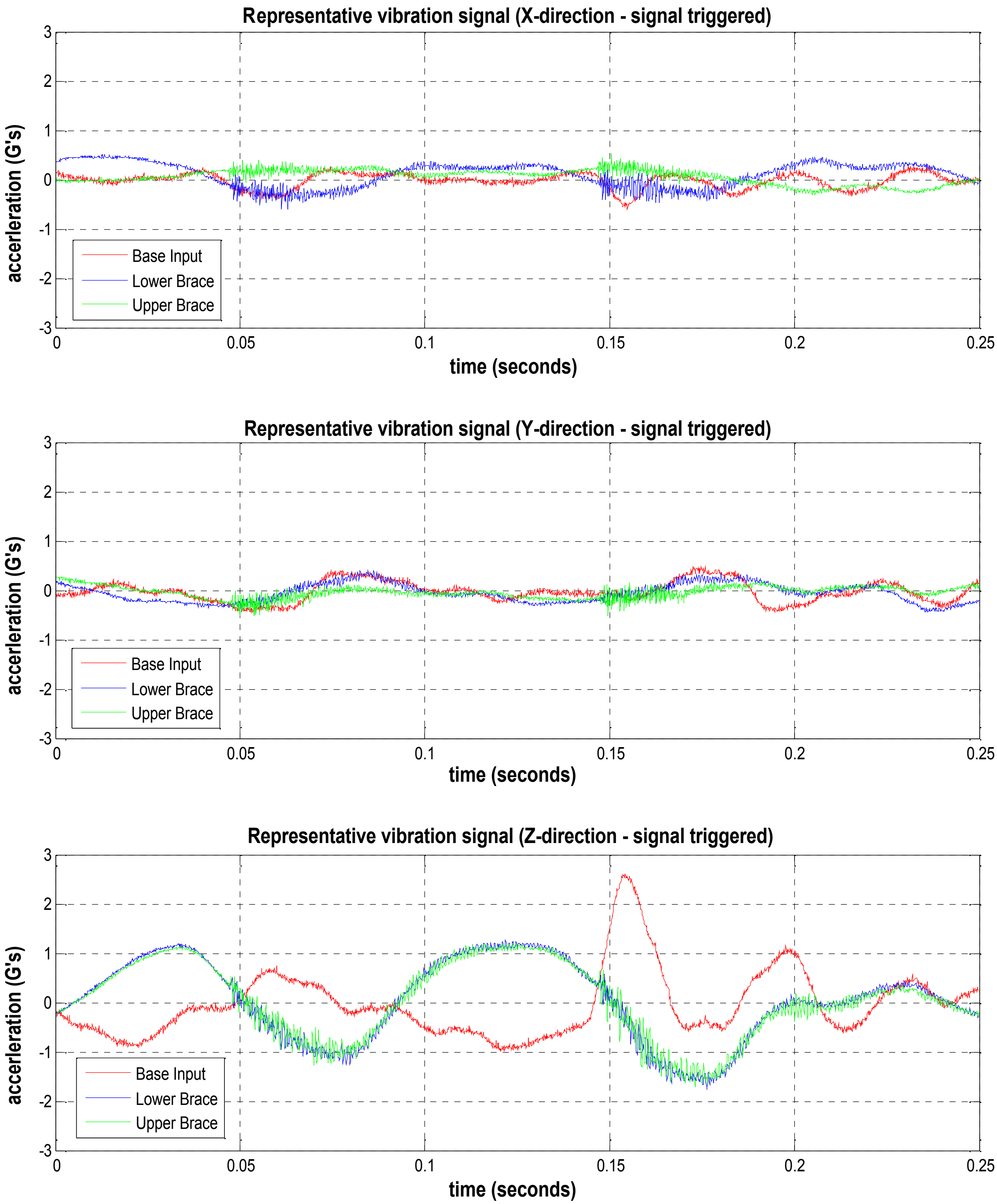


Figure 8: Representative vibration signal for "Signal Triggered" event

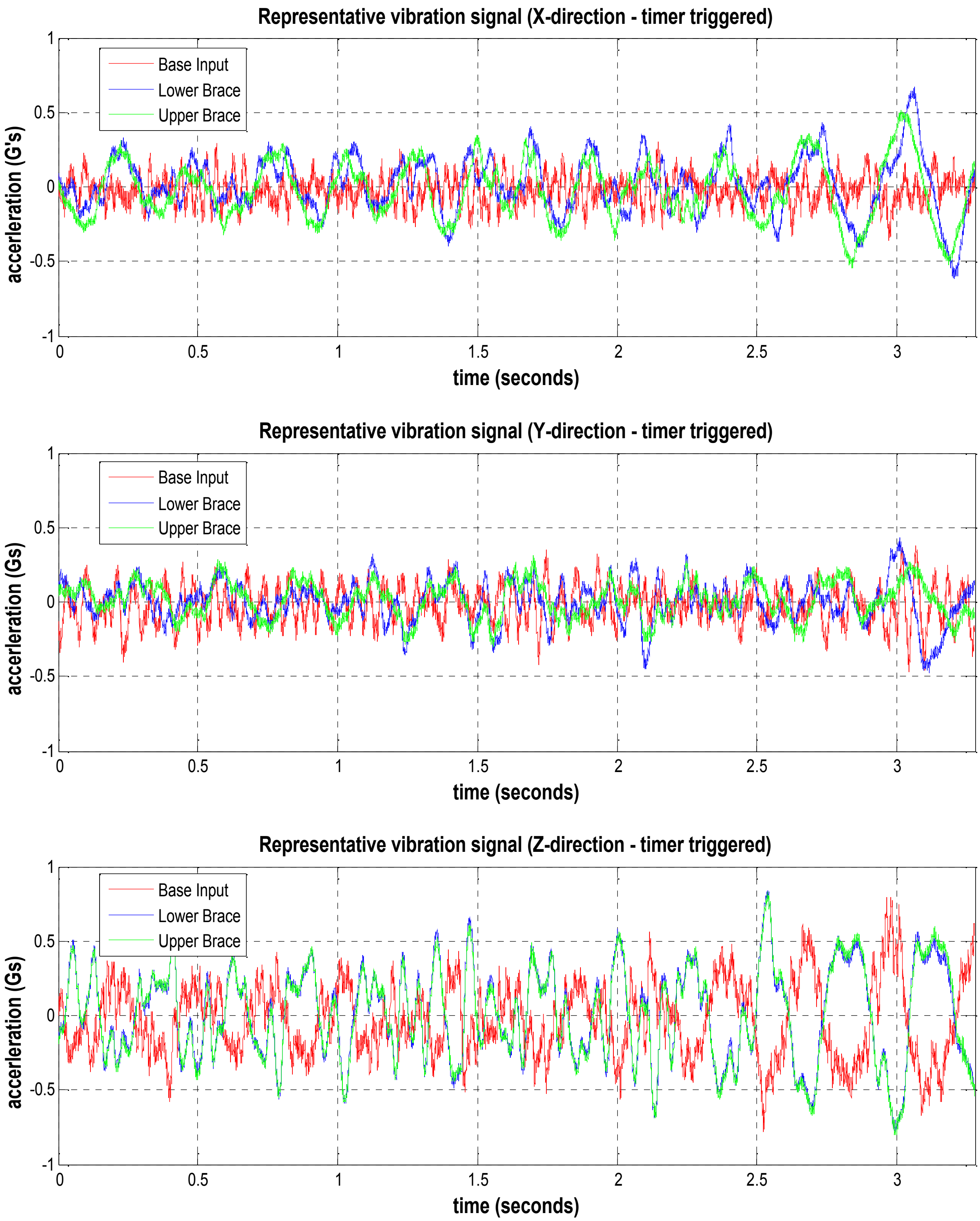


Figure 9: Representative vibration signal for "Timer Triggered" event

Shock Results:

Shock is generally characterized by a signal with a short pulse width of high amplitude having a relatively low Grms value. Calculation of a crest factor, which is the ratio of the peak magnitude to the rms value of the signal, is a common way to distinguish a shock pulse from a transient vibration segment. For the data collected, a crest factor of 5 was used to distinguish the shocks.

In the case of the klystron hardware, a large percentage of the shocks appear to be caused from components bumping together or the klystron unit running out of displacement on the cable springs and impacting something. Figure 10 below shows a representative shock pulse that was captured on the klystron hardware. Note that in this pulse there is a large input pulse in the Z-direction from the base input that appears to initiate the shock input on the klystron hardware, roughly 0.1 seconds later. Additional representative shock pulses are shown in Figures 11 – 14.

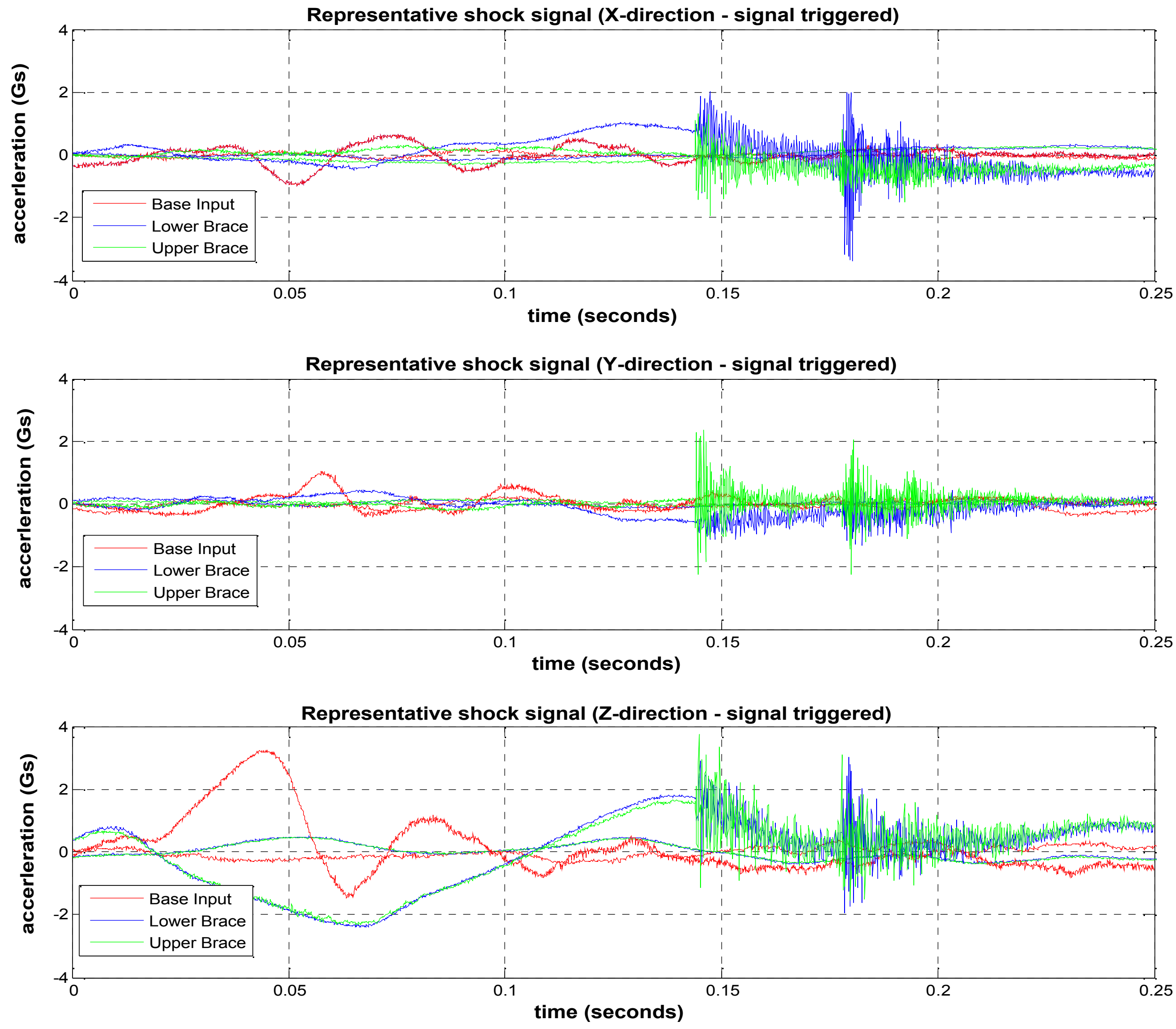


Figure 10: Representative shock pulse to klystron unit.

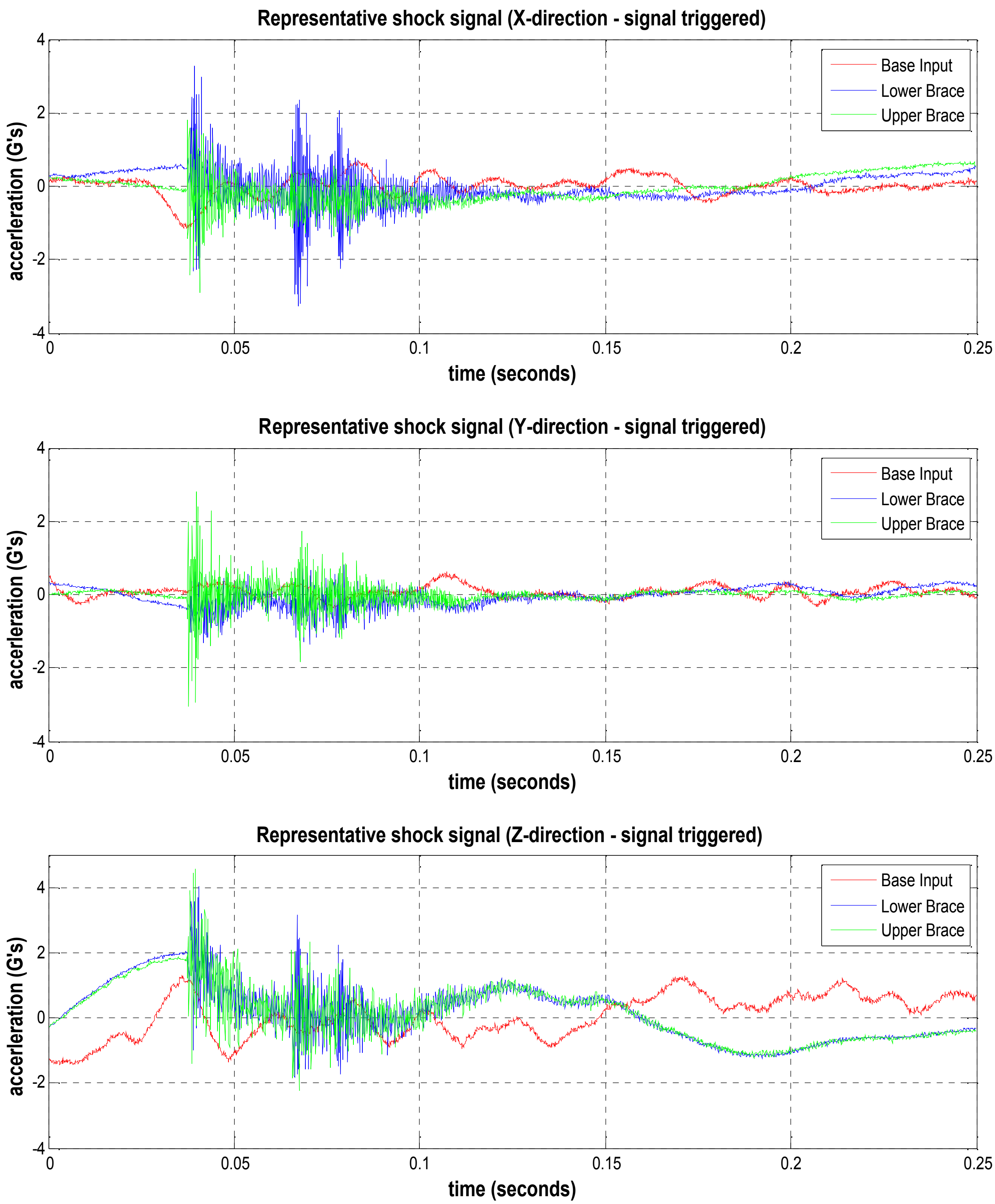


Figure 11: Representative shock pulse to klystron unit.

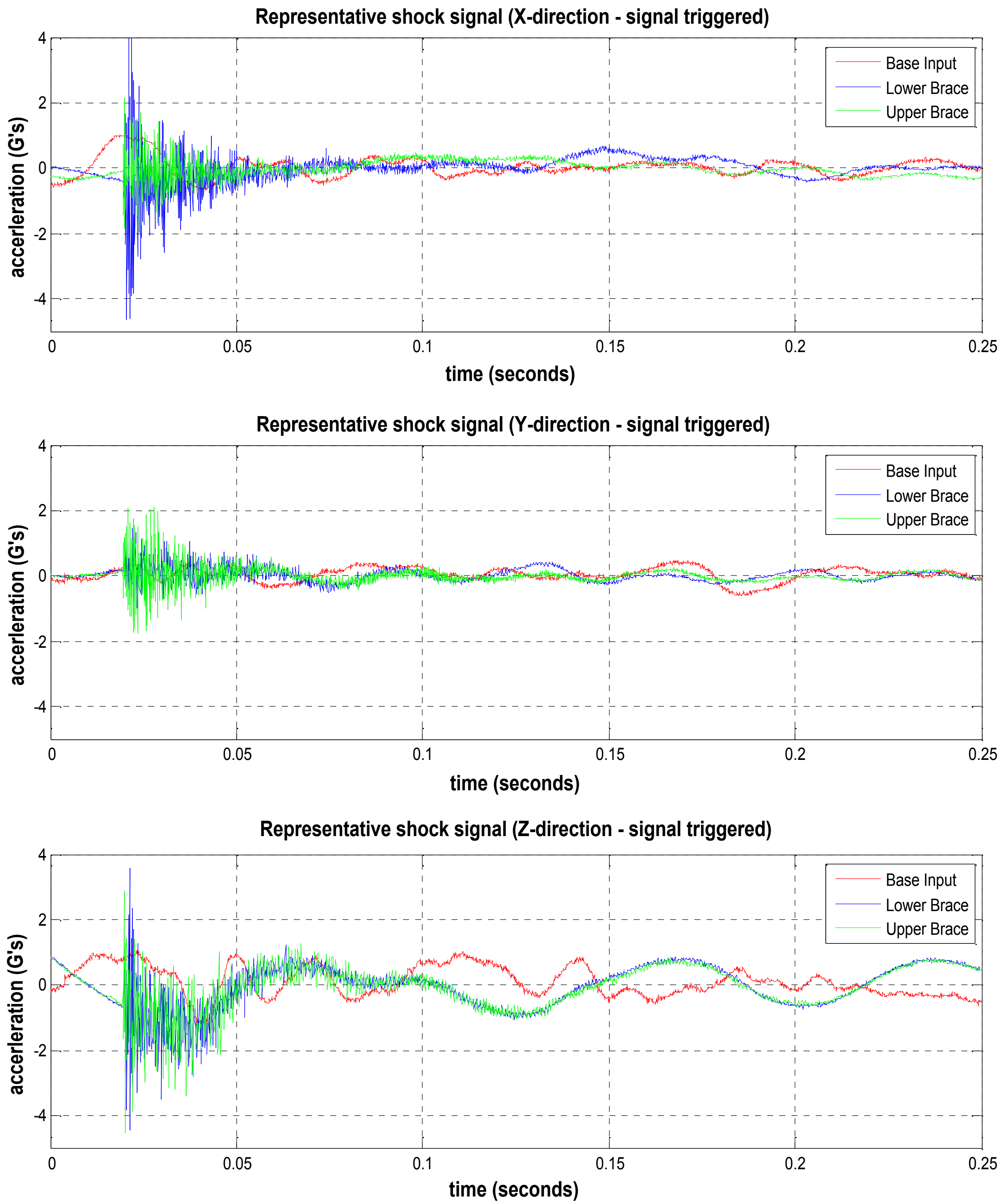


Figure 12: Representative shock pulse to klystron unit.

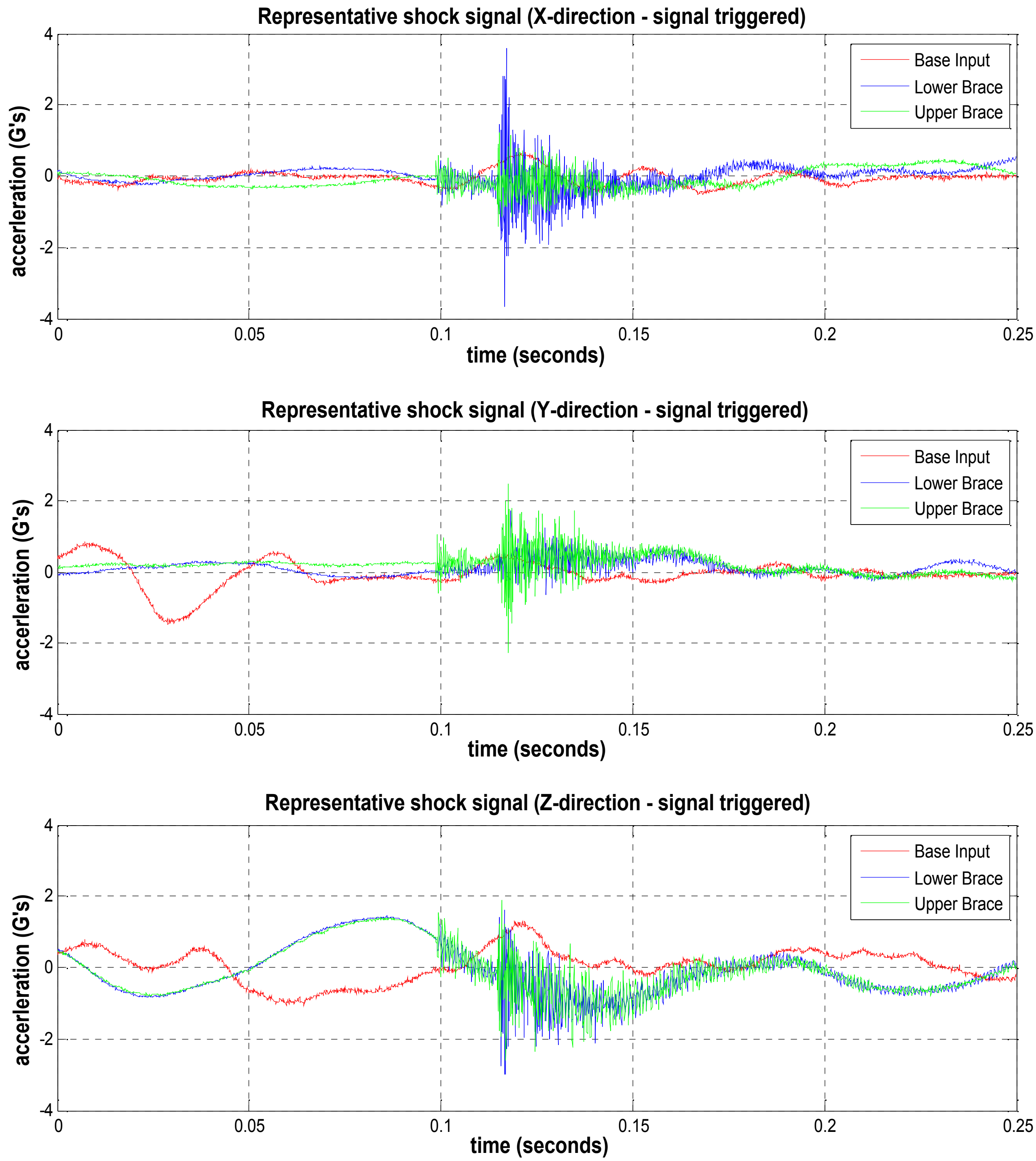


Figure 13: Representative shock pulse to klystron unit.

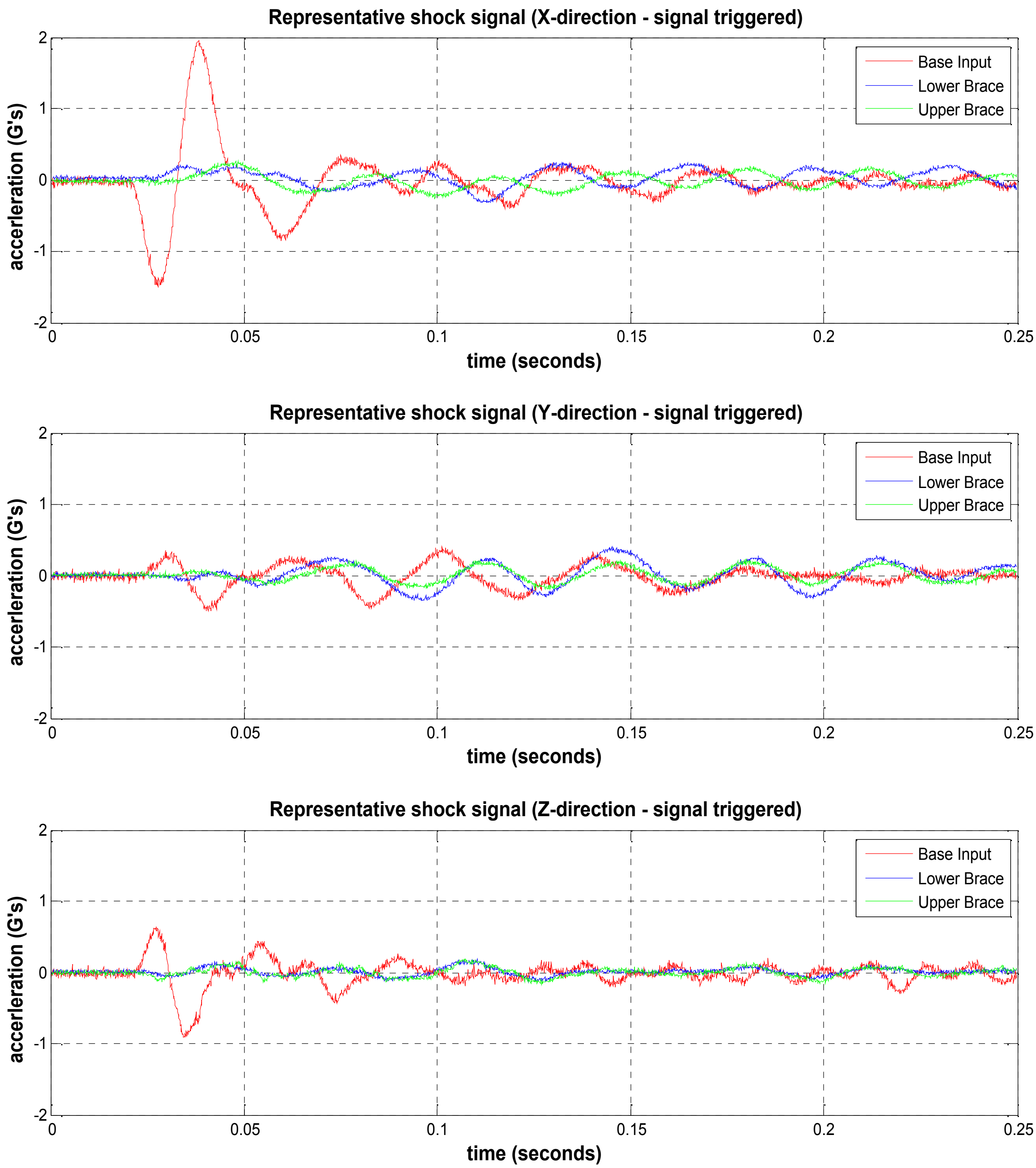


Figure 14: Representative shock pulse from base input showing no impact to klystron hardware.

Discussion of Results:

The table below summarizes the general vibration and shock input collected during the trip from SLAC to LLNL main site, followed by a brief discussion of the individual axis results.

Vibration	**Timer Triggered Data**			**Signal Triggered Data**		
Description	**X-dir.**	**Y-dir.**	**Z-dir.**	**X-dir.**	**Y-dir.**	**Z-dir.**
Base Input – mean Grms	0.07	0.10	0.14	0.15	0.20	0.38
Base Input – upper envelope Grms	0.16	.24	.33	0.54	0.60	1.18
Lower Brace – mean Grms	0.12	0.11	0.20	0.26	0.19	0.55
Lower Brace – upper envelope Grms	0.29	0.25	0.48	0.80	0.55	1.43
Upper Brace – mean Grms	0.16	0.87	0.19	0.29	0.13	0.53
Upper Brace – upper envelope Grms	0.29	0.19	0.46	0.64	0.54	1.37

Shock	**Base Input Peak-G**			**Lower Brace Peak-G**			**Upper Brace Peak-G**		
Description	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Largest shock at base input (signal #205 – 5/1/2012 4:05 pm)	1.0	1.0	3.3	3.4	1.3	3.0	2.0	2.4	3.8
Largest shock at lower brace (signal #119 – 5/1/2012 3:21 pm)	0.8	1.1	2.4	5.5	1.1	4.6	2.1	2.4	3.9
Largest shock at upper brace (signal #176 – 5/1/2012 3:21 pm)	1.2	0.6	1.5	3.3	1.4	4.0	2.9	3.1	4.6

Total number of shocks recorded on klystron unit with Peak-G's over 1	212
Number of shocks on klystron unit with Peak-G's larger than 3	8
Number of shocks on klystron unit with Peak G's between 2 - 3	10
Number of shocks on klystron unit with Peak G's between 1.5 - 2	20

X-axis Analysis

The PSD data for the timer triggered data shows a significant resonant peak around 3.5 - 4 Hz. It is not seen as easily in the signal triggered data because of the time window which limited the lowest frequency to only 4 Hz (1/time frame = 1/.25 sec = 4 Hz). This resonant peak appears to be associated with the cable spring isolators because the base input at that frequency range is almost 2 orders of magnitude lower. The timer triggered data shows good attenuation after the resonant peak, which is to be expected and is indicative of a well isolated system. Even with the amplification at resonance, the Grms values are generally low (~0.3 Grms) and wouldn't merit much concern as it relates strictly to a vibration damage potential. However, the signal triggered data suggests impacts in the X-direction, as discussed previously. This can be seen in the high frequency content of the PSD, but is confirmed in the time histories, which show periodic transient shocks. Many of the shocks in the X-direction simultaneously have a similar magnitude as those in the Z-direction, which suggests a pitching motion of the klystron unit on the isolator springs.

Y-axis Analysis

The Y-axis data is very similar to the X-axis data and shows the same resonant peak around 3.5 - 4 Hz, which is to be expected given the symmetry of the cable spring isolators. There is some additional energy in the 10 – 30 Hz range that isn't present in the X-data, but overall it doesn't affect the overall Grms by much. As for shocks, generally speaking the Peak-G shock levels tend to be smaller in the Y-direction than either the X or Z direction.

Z-axis Analysis

As might be expected, the Z-axis data shows the largest response for all sensors. The resonant peak at 3.5 – 4 Hz is also present in this data and all three sensors shows the approximately the same magnitude. Typically this would indicate a rigid body mode, where all sensors are moving in unison, however much of the timer triggered data shows the base input being 180 degrees out of phase from the sensors on the klystron. There is currently no explanation for this. The higher frequencies are attenuated but around 15 – 16 Hz there is a resonant peak roughly an order of magnitude over the base input which does cause the response of the klystron to be slightly more than the base input. Shock inputs in the Z-direction seem to be the highest, but often couple with the X-shocks indicating a pitching motion as stated earlier.

Summary and Recommendations:

Vibration data collected during shipment of the klystron unit shows some level of amplification over the base input in all directions but it is not substantial. Vibration base input levels are comparable to data collected from other trucks making commutes on interstate highways. Vibration levels between 0.7 and 1.2 Grms are common for commercial air ride trucks in the Z-direction. The fragility of the hardware should be understood when determining whether the levels measured are acceptable.

Regarding measured shocks, it is recommended to take a closer look at the isolation hardware and the clearance levels of any nearby components that could impact from a large displacement. Shocks measured during transit are higher than they need to be and contain high frequency content suggesting impacts or collisions of hardware against hard surfaces. Shocks measured in the X and Z direction appear to be the highest, which may indicate a pitching motion of the klystron unit on the cable spring isolators.